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ASSESSMENT OF BORON STEELS FOR ARMY USE

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ABSTRACT

The increasing dependence of the United States on imports of steel alloying elements may cause serious shortages of alloy steels needed for Army hardware during a future national emergency. In this report the possible use of boron steels as substitutes for alloy steels is considered for applications where engineering properties can be retained. Conservation benefits and standardization status are also indicated. It is concluded that boron steels can be substituted for alloy steels in most applications and recommendations are made to facilitate their use.

CONTENTS

INTRODUCTION

The world population growth coupled with the increasing appetite of the human race for energy, food, and manufactured goods have caused growing alarm about the adequacy of the earth's limited resources.[1] The petroleum situation has been well publicized from the energy demand viewpoint, and the incompatibility of current and projected use rates with reserves is well known.[2] Also well known are the potential energy alternatives from coal, nuclear, and solar resources even though a national policy of conversion to utilize these alternatives is obscure.[3] Food production for most of the present world population is barely adequate, and is grossly inadequate in many parts of the world. World population has increased to the point where the food output of the Mississippi basin is no longer adequate to compensate for poor crops in other countries, and even the production of fertilizer is not adequate for increased farm productivity.

Each day seems to bring into focus a new shortage in manufactured products. Newsprint shortages have accelerated the recycling of waste paper, and the shortage of ethylene glycol antifreeze caused by increased production of polyester fabrics has been publicized. There are many other shortages of materials from which goods are manufactured which have not been widely broadcast. These have, however, intensified scrap recycling activity as well as exploration for new sources of supply.[3] In many cases these shortage problems have been intensified by foreign government decisions to raise base prices or to decrease exports when those governments control major world reserves.

In the case of alloy steels, the main shortage is not with iron ore but rather with the alloying elements used to harden steels as well as to provide certain other desirable properties.[3] Most of the alloying elements are not available in this country and must be imported.[4] During World War II and again during the Korean conflict, the domestic steel industry was forced to undertake major alloy conservation programs due to the inadequacy and uncertainty of supply of needed alloying elements.[5,6] The success of these alloy conservation programs was due in large part to the discovery that the steel microstructure (rather than the composition per se) is the chief factor which controls steel properties. This permitted some reduction in alloy content, provided that the steels were heat treated to a tempered martensite microstructure. It was also learned that the element boron has a major effect in promoting hardenability in steels and that it could be substituted for some alloying elements to achieve significant alloy conservation.[7]

1. OSBORNE, F. *The Limits of the Earth.* Little Brown & Co., 1953.
2. Scientific American, September 1970.
3. *Materials Needs and the Environment Today and Tomorrow.* Final Report of the National Commission on Materials Policy, June 1973.
4. Materials Yearbook, 1972, v. 1, U.S. Department of the Interior, U.S. Government Printing Office, 1974.
5. DIGGES, T. G., and REINHART, F. M. *Investigation of Boron in Armor Plate.* National Bureau of Standards OSRD Report No. 3020, 3378, 4022, 4181, December 1943 to October 1944.
6. CARBONARO, P. A. G., and AHEARN, P. J. *Utilization of Special Steel Addition Agents to Gun Tubes and Breech Rings.* Army Materials and Mechanics Research Center, RPL 2, July 1954.
7. GLEN, J. *The Effect of the Major Alloying Elements and Boron on the Hardenability of Steel.* Iron and Steel Institute, Special Report 36, 1946.

Since World War II the development of jet engines and increased use of stainless steels have caused large consumption increases in elements such as nickel, chromium, molybdenum, cobalt, columbium, and tungsten.[4] Many of these elements are also needed for other alloy steels, and in several instances consumption demands have been met only by release from the national stockpiles.[4] Depletion of the stockpile together with increasing requirements have caused grave concern of the ability to meet future demands.[3] Thus attention has been directed again to the question of whether use of boron can be increased to ease future steel alloy shortage problems.[8]

The purpose of this report is to assess briefly the technology of boron alloy steels to determine if increased use of boron steels by the Army could provide conservation benefits without sacrifice of steel properties or hardware reliability.

METALLURGICAL CONSIDERATIONS

The most important attribute of an alloy steel is its capacity for hardening by thermal treatment, commonly referred to as hardenability. This attribute has a dual significance; it is important in relation to the magnitude or level of attainable strength, and also in relation to the degree of toughness achievable through heat treatment to a desirable microstructure, usually tempered martensite. The toughness aspect of hardenability is of great practical importance since attainment of high strength is of little value unless sufficient toughness exists to meet service requirements without risk of premature fracture.[9] It is most important to realize that "hardenability" refers to the depth of hardening or to the size of the piece which can be fully hardened, rather than to the hardness level per se. The hardness level attainable in an alloy steel is almost entirely dependent on the carbon content, while hardenability is primarily dependent on the alloy content. (Austenite grain size, however, does affect hardenability.[9])

To achieve the best combination of strength and toughness in alloy steels it is necessary to transform the microstructure from austenite to the lower temperature transformation product martensite (lower bainite may also be satisfactory for certain applications).[10] As the carbon content of a steel is reduced transformation of the austenite on cooling begins sooner and proceeds more rapidly.[11] This prevents attainment of a martensite microstructure except near the steel surface. Plain carbon steels have low hardenability, and the lower the carbon content, the lower the hardenability. On the other hand, increasing the alloy content delays both the start of transformation and the transformation rate. Thus, alloy steels have more hardenability than carbon steels. Furthermore, the effect is cumulative so that addition of alloying elements to impart other desirable steel properties also increases hardenability.[12] Multiplying factors

8. *Boron Steels - A Brief History of Development and Use.* Army Materials and Mechanics Research Center, AMMRC SP 74-2, April 1974.
9. GROSSMON, M. A. *Elements of Hardenability.* American Society for Metals, 1953.
10. *Metals Handbook.* American Society for Metals, Eighth Edition, v. 1, 1961, p. 233.
11. U.S. Steel Corporation. *Atlas of Isothermal Transformation Diagrams.* 1971.
12. BAIN, E. C. *Functions of Alloying Elements in Steel.* American Society for Metals, 1939.

for estimating the effect of additions of alloying elements in the hardenability of alloy steels are contained in Figure 1.[13] If more than one alloy addition is made, the base composition is multiplied successively by the hardenability factor for each alloying element. Thus, it is evident that small additions of each of several alloys have a greater hardenability effect than a large addition of a single element.

The sole purpose in adding boron to a steel is to increase its hardenability.[14] The addition of boron permits replacement or reduction in alloying elements whose purpose was also to provide hardenability. The behavior of boron is unique in that the hardenability increase is independent of the amount of boron present, provided that the amount present exceeds 0.0008%.[7] Boron can also replace several hundred times its own weight of nickel, chromium, molybdenum, or manganese without reducing hardenability, thus providing great potential for alloy conservation.[7] Boron seems to have little effect on steels of eutectoid composition. However, as carbon content decreases below eutectoid composition, the effectiveness of boron increases almost linearly as indicated in Figure 2.[14] The data for Reference 14 was obtained from the large sample of commercial heats (15 to 190 tons) of the compositions listed in Table 1 covering the range of 0.12% to 0.95% C. This high potency of boron at low carbon levels is of great importance since most highly alloyed steels are below 0.40% carbon, including AISI grades 23XX, 25XX, 33XX, 43XX, 48XX, and 93XX. These six grades are fertile fields for alloy conservation programs and have been explored to some extent during the immediate post World War II period.[15]

The selection of a boron steel depends on the existence of hardenability bands from Jominy tests of samples from commercial heats. Materials and design engineers use hardenability band graphs to insure that through-hardening can be achieved in the section thickness of the part. A sample hardenability band graph is contained in Figure 3 for 4340H and 86B45H steels. Note that 86B45H steel could be substituted for 4340H based on equivalent hardenability for section thickness up to at least 2 inches. For greater section thicknesses the application requirement details would permit one to decide whether the greater scatter of the 86B45H hardenability band would be acceptable. In any event, note from the compositions in the figure that use of 86B45H in lieu of 4340H would permit significant savings of nickel and chromium, even though a slight increase in manganese consumption might result.

One of the great advantages of the addition of boron to steel is that it seems to have little influence on anything but hardenability. It has been shown that boron does not influence thermodynamic free-energy changes occurring during austenite transformation, nor does it affect the temperature or rate of formation of martensite, lower bainite, carbides, or pearlite.[16] Thus, as long as low temperature transformation products are desired (martensite and lower bainite), boron

13. McGANNON, H. E. *The Making, Shaping, and Treating of Steel.* U.S. Steel Corporation, 1964.
14. RAHRER, G. D., and ARMSTRONG, C. D. *The Effect of Carbon Content on the Hardenability of Boron Steels.* Trans. ASM, v. 40, 1948.
15. *Boron Steels.* First MAB Report, Metal Progress, v. 60, August 1951.
16. FISHER, J. C. *Influence of Boron on the Hardenability of Steels.* Trans. AIME, v. 200, 1954.

additions to steel would not require changing heat treatment schedules in any way. In fact, since boron seems to displace the transformation curve to the right, the possibility of quench cracking is reduced.[11]

The questions of how much boron is needed, and what is the optimal amount, have been explored quite thoroughly.[17] The optimum boron content has been determined to be 0.0033%, but amounts up to 0.005% do not decrease hardenability.[17]

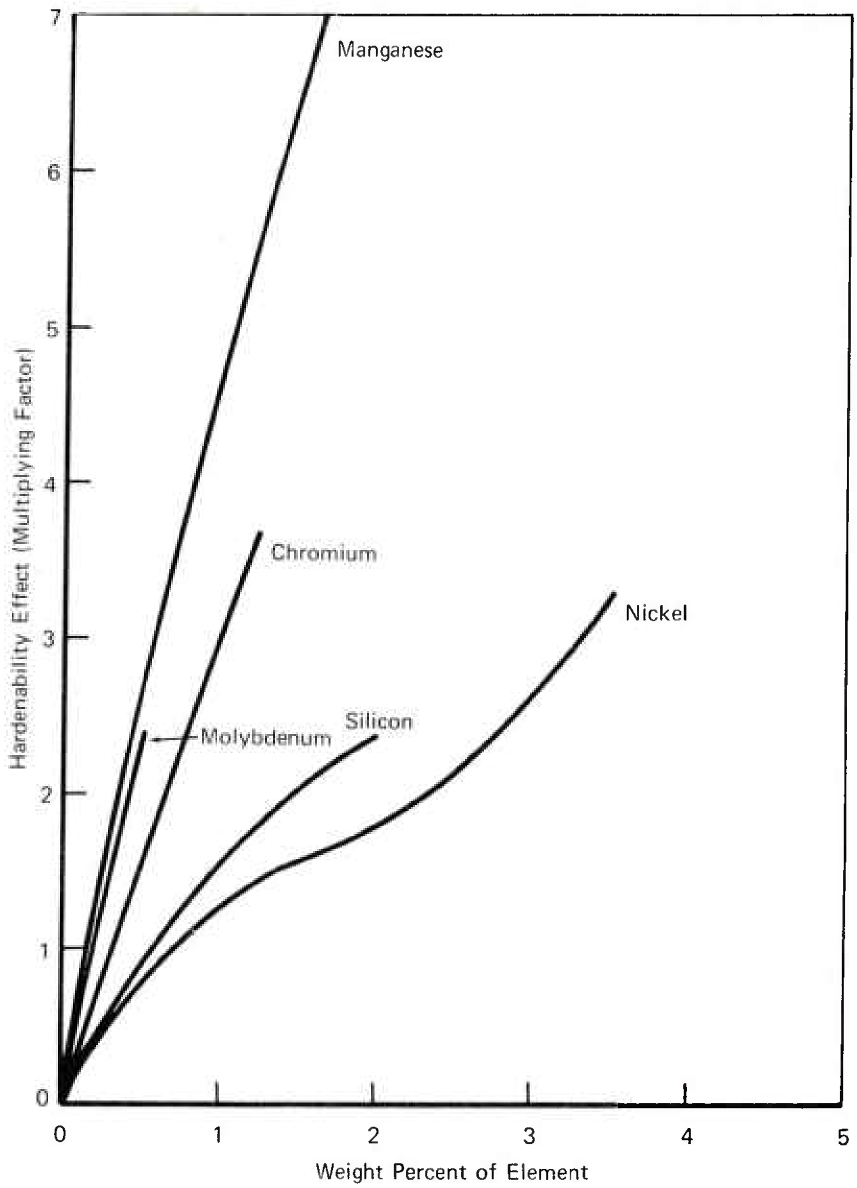


Figure 1. Effects of alloying elements on hardenability. (Reference 13).

17. SHYNE, J. C., MORGAN, E. R., and FREY, D. N. *The Optimum Boron Content for Hardenability.* Trans. ASM, v. 48, 1956.

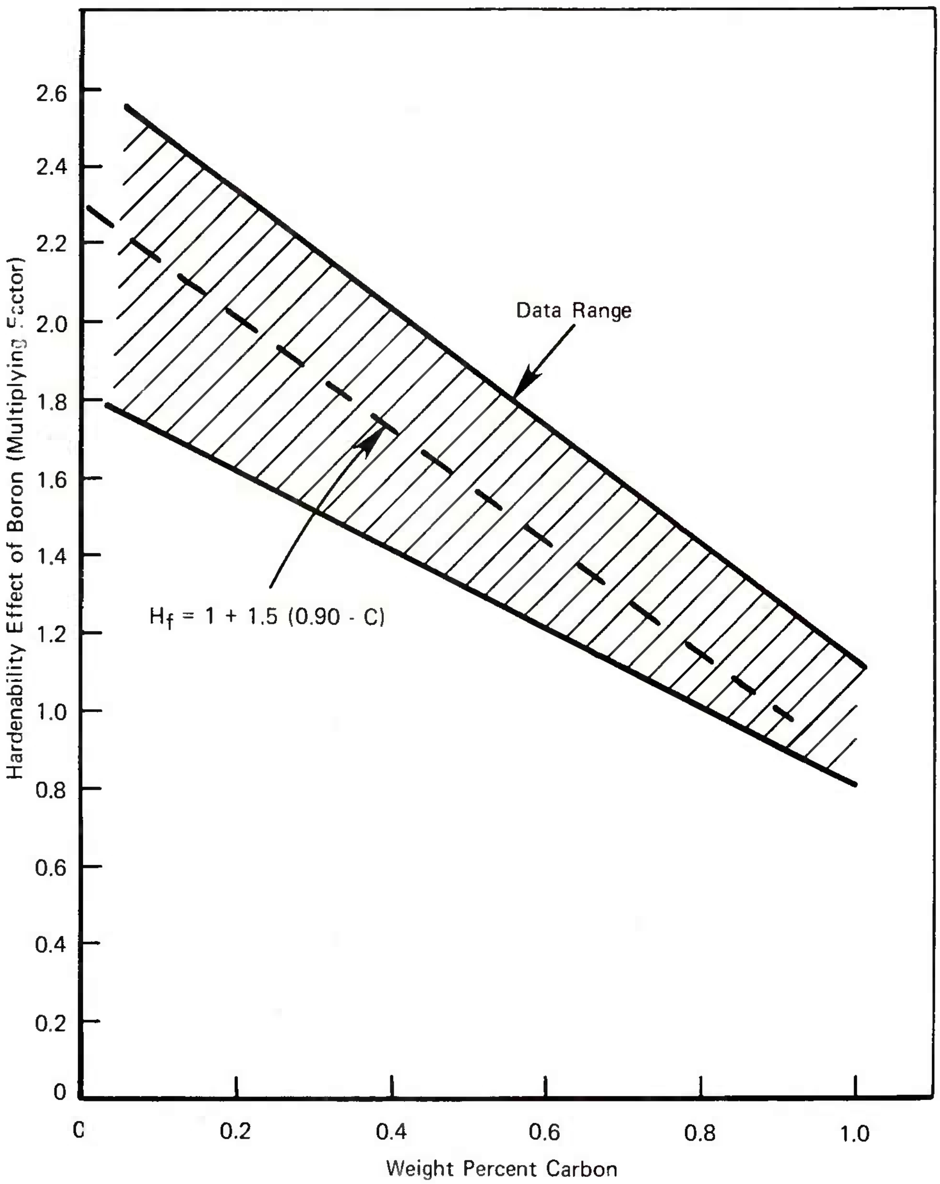


Figure 2. Effect of boron on hardenability of commercial heats of steel. (Reference 14).

As a practical matter, 0.001% to 0.003% boron additions are perfectly adequate. However, it has been noted that O_2 and N_2 must be taken care of (degassing) prior to the addition of boron to the melt. The addition of 2 pounds of aluminum per ton of steel to provide a killed steel is adequate for this purpose.[14] It has also been noted that boron amounts in excess of 0.005% frequently cause steel temper embrittlement as well as hot shortness and should therefore be avoided.[17]

Table 1. COMMERCIAL HEATS (15 TO 180 TONS) OF STEELS EMPLOYED IN REFERENCE 14

Carbon Steels	Alloy Steels
1020 and 10B20	4615 and 46B15 (2 heats each)
1025 and 10B25 (3 heats each)	4315 and 43B15
1040 and 10B40	4620 and 46B20
1045 and 10B45 (6 heats each)	8615 and 86B15
1050 and 10B50	8620 and 86B20
1065 and 10B65	9430 and 94B30
1075 and 10B75 (3 heats each)	8630 and 86B30
1095 and 10B95 (2 heats each)	Cr-Mo and Cr-Mo-B
	Ni-Cr-Mo and Ni-Cr-Mo-B (3 heats each)

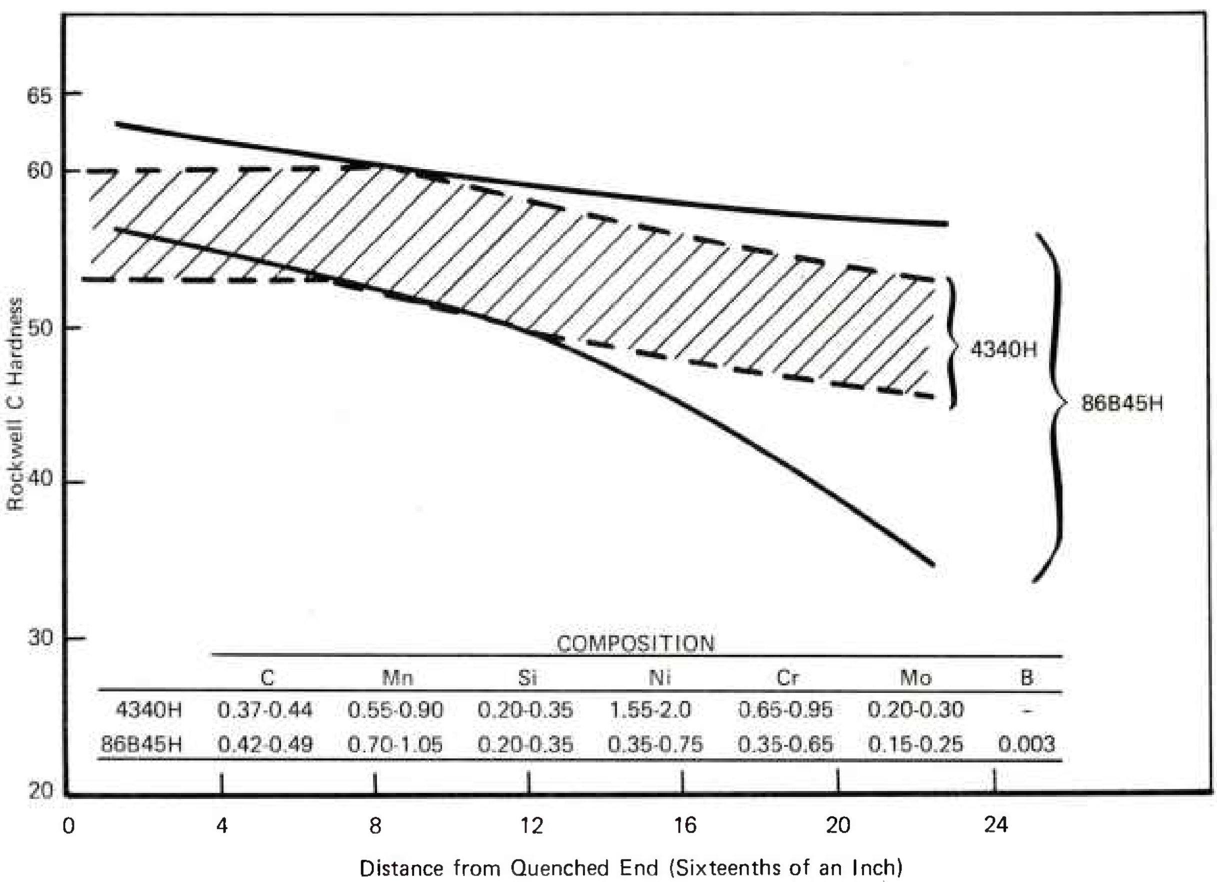


Figure 3. Hardenability bands for 4340H and 86B45H steels.

Incidentally, boron does not strengthen ferrite.[13] This is of particular importance in that the steel to which boron is added is *not* more difficult to form to desired shapes prior to heat treatment. Thus boron steels possess the same workability as non-boron steels of the same compositions.

PROPERTIES

It has been established that all constructional steels, when quenched to 90% to 100% martensite and tempered, will have the same mechanical properties at any given hardness level within the range of 200 to 400 Brinell hardness number.[15] A sample tabulation to illustrate the point is presented in Table 2.[15] It is recognized that for special processing procedures to achieve higher strength,[18] or to achieve ultrafine grain sizes,[19] the above generalization may be invalid. However, these special processing procedures represent the exception rather than the rule. It is important to note that the steels listed in Table 2 were heat treated in thin sections so that tension specimens were all of essentially 100% martensite. These steels differ in hardenabilities, and in heavier sections some would not provide equivalent properties since they would have higher temperature austenite transformation products in their microstructures. As nonmartensitic transformation products increase in the microstructure, large changes occur in toughness, or in ductile-brittle transition temperatures.[20] Figure 4 is reproduced from Reference 20 to illustrate the point for a single alloy steel. In Figure 5[20] the point is illustrated more dramatically for three alloy steels, one of which is a boron steel. Of more significance, however, is the fact that all three steels exhibit the same fracture transition temperature when at 100% martensite. Furthermore, the addition of boron within the limits previously discussed does not affect the ductile-brittle transition temperature for martensite microstructures.[20] It therefore follows that boron additions of 0.001% to 0.003% will increase hardenability without embrittlement provided that the steel is quenched to martensite, tempered, and quenched from the tempering temperature.[20]

Table 2. PROPERTIES OF COMMERCIAL STEELS AT 150,000 PSI YIELD STRENGTH

Grade	Quench	Grain Size	Temper (°F)	Chemistry (Weight Percent) C	Mn	Si	Ni	Cr	Mo	UTS (ksi)	Elon. (%)	R.A. (%)	Brinell Hardness Number
6130	H_2O	6-8	1025	0.33	0.61	0.18	-	1.03	-	160	18	58	341
2330	H_2O	6-8	840	0.31	0.70	0.26	3.45	-	-	163	15	61	331
4140	H_2O	6-8	925	0.31	0.53	0.28	-	1.04	0.20	165	15	57	331
8630	H_2O	6-8	950	0.30	0.80	0.27	0.65	0.48	0.18	160	16	64	331
86B30	Oil	6-8	840	0.33	0.62	0.24	0.31	0.28	0.13	162	17	60	331
1340	Oil	6-8	925	0.43	1.70	0.23	-	-	-	160	15	55	331
3140	Oil	6-8	925	0.39	0.76	0.25	1.20	0.65	-	167	16	61	331
4140	Oil	6-8	1020	0.41	0.85	0.20	-	1.01	0.24	165	16	55	331
4340	Oil	6-8	1050	0.41	0.67	0.26	1.77	0.78	0.26	163	17	58	341
4640	Oil	6-8	975	0.41	0.70	0.24	1.83	-	0.28	163	17	56	341
8740	Oil	6-8	1100	0.39	1.00	0.25	0.53	0.52	0.28	160	16	57	331
9440	Oil	6-8	925	0.39	1.06	0.28	0.39	0.32	0.11	165	16	59	331
4150	Oil	7-8	1160	0.50	0.76	0.21	-	0.95	0.21	165	15	54	341
5150	Oil	7-8	1000	0.49	0.75	0.25	-	0.80	-	160	15	53	331
6152	Oil	6-8	1125	0.49	0.78	0.29	-	1.00	-	160	16	51	331
8750	Oil	6-8	1040	0.51	0.80	0.24	0.53	0.52	0.25	166	14	50	341

18. ZACKAY, V. F., et al. *The Enhancement of Ductility in High Strength Steels.* Trans. ASM Quarterly, v. 60, June 1967, p. 252.
19. BURKE, J. J., and WEISS, V. *Ultra Fine-Grain Metals.* 16th Sagamore Army Materials Research Conference, Syracuse University Press, 1970.
20. LARSON, F. R. *Effect of Microstructure on the Impact Properties of Some Commercial Alloy Steels With and Without Boron.* Army Materials and Mechanics Research Center, Technical Report WAL TR 310/215, April 1958.

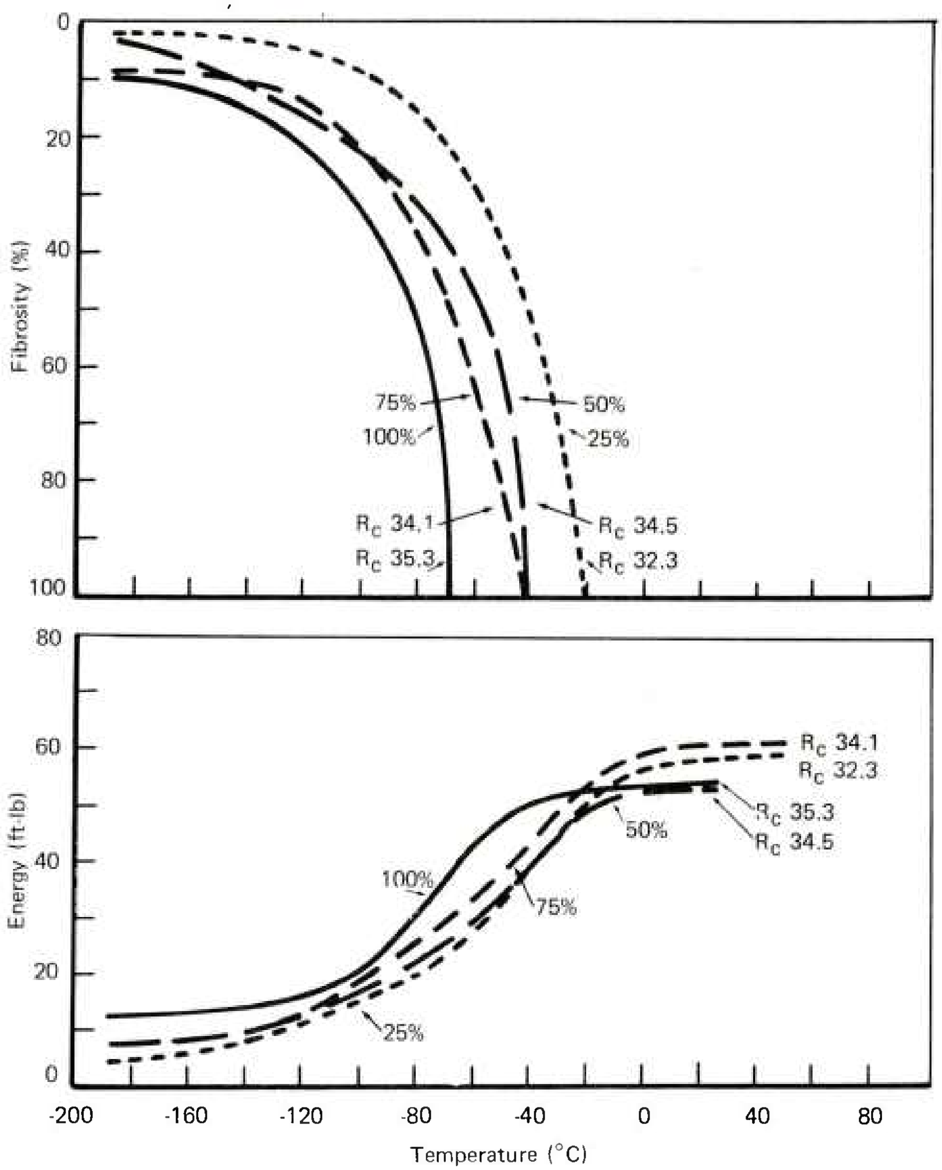
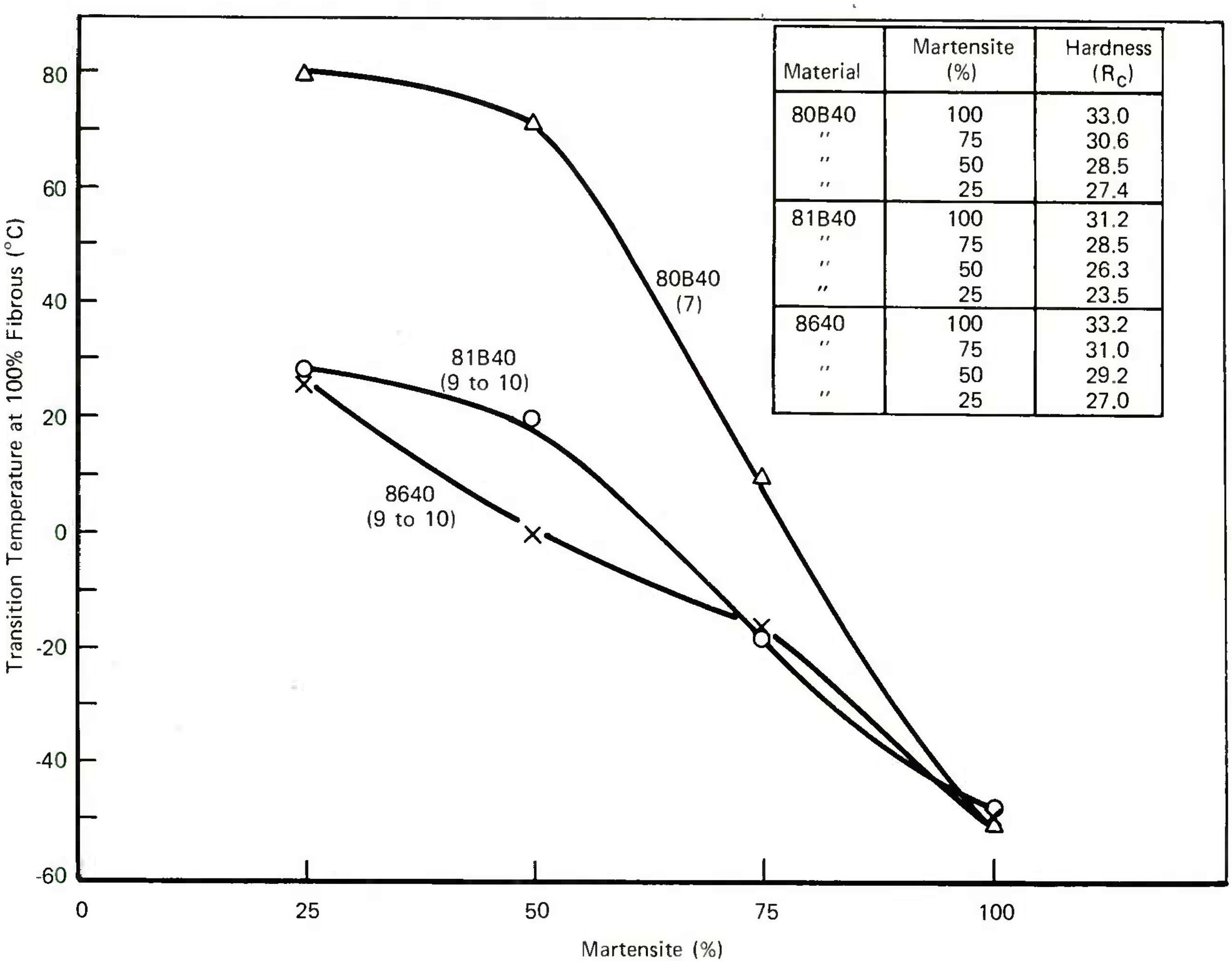


Figure 4. Effect of testing temperature upon the energy and fracture appearance of various microstructures of 8740 steel tempered at 1100 F. Hardness and percent martensite indicated on curves.

The previous statement assumes that good metallurgical practice is followed. It has been shown that boron additions in excess of 0.005% cause hot shortness.[17] Powers and Carlson[21] added 0.0034% boron to a 0.25C-1.7Mn steel to which two pounds of aluminum per ton of steel had previously been added. The dramatic increase in hardenability due to the boron was demonstrated. Specimens which were temper embrittled at 900 F for 100 hours demonstrated the greater temper embrittlement susceptibility of boron steels. Samples of the boron steel which had not been temper embrittled had the same impact properties at the same hardness level as non-boron steels.

21. POWERS, A. E., and CARLSON, R. G. *The Effect of Boron on Notch Toughness and Temper Embrittlement.* Trans. ASM, v. 46, 1954.



Material	Martensite (%)	Hardness (R_c)
80B40	100	33.0
"	75	30.6
"	50	28.5
"	25	27.4
81B40	100	31.2
"	75	28.5
"	50	26.3
"	25	23.5
8640	100	33.2
"	75	31.0
"	50	29.2
"	25	27.0

Figure 5. Comparison of impact transition temperatures for two boron and one non-boron steel as a function of martensite (ASTM grain size marked in parenthesis).

Wilcox reported that boron additions to NE 8640 steel and a 0.35C-1.5Mn-0.3Mo steel significantly increased hardenability.[22] He also demonstrated that ductility and toughness values were equivalent for the same strength levels. Where through-section hardenability was not possible and nonmartensite transformation products occurred in the microstructure, boron steels had lower impact values than the non-boron grade (in some cases very much lower values). This would be expected, based on Figure 5.

Rather than determine the effect on properties of the addition of boron to a specific composition, boron and non-boron steels with equivalent hardenabilities have been evaluated for mechanical properties.[23] The 4130 and 86B30 steels having equal hardenability bands were quenched to martensite and tempered to a hardness

22. WILCOX, R. *Effect of Boron on the Mechanical Properties of Low Alloy Steels.* J. Iron-Steel Inst., v. 173, 1953, p. 406-419.
23. IMHOFF, R. N., and PAYNTER, J. W. *Some Metallurgical Characteristics of Medium Carbon Boron-Treated Steels.* Metal Progress, v. 63, March 1953.

of 30 Rockwell C. Tensile properties (strength and ductility) were equal, and Charpy V-notch transition curves were also identical except that 4130 had somewhat higher impact energy values at temperatures below -65 F. Two other steels with equivalent hardenability (Figure 3) which were evaluated were 4340 and 86B45. Tensile properties were the same for both steels at each strength level examined up to 260,000 psi UTS. At the same strength level, Charpy V-notch transition curves for the two steels were identical down to temperatures of -65 F. For all Army equipment where ambient temperatures below -65 F are not encountered, these steels could be interchanged.

A number of other characteristics of boron steels have been examined and it appears that except for hardenability a boron steel behaves as if it were a non-boron steel of the same composition. Boron steels have been shown to exhibit the same machinability as non-boron grades.[24,25] The presence of boron does not change either the carburization rate or the decarburization rate, thus permitting use of boron for alloy conservation in carburizing grades of steel.[26,27] Welding of boron steels is straightforward and is as if the base composition without boron were being welded.[28,29] Certain elevated temperature properties of boron steels are not affected by the presence of boron.[30] However, since creep properties are dependent on alloy content, use of boron to conserve alloying elements may affect creep deleteriously, and may obviate use of boron steels for some elevated temperature applications.

CONSERVATION BENEFITS

Alloy Element Availability

The principal alloying elements used in alloy steels of structural grades are manganese, nickel, chromium, molybdenum, silicon, and vanadium. Other alloying elements, such as tungsten, cobalt, and titanium, which are added to enhance magnetic behavior, elevated temperature properties, etc., are excluded from this report. A question of basic economic significance concerns the sources of these elements in quantities required for national consumption. Imports of alloying elements in peacetime are a part of normal international trade, but domestic availability may be of great strategic significance in wartime. Imports may be cut off, and some steel alloying elements may be available only in scrap steel, requiring major changes in alloy steel chemistry. In this context, use of boron to maintain hardenability, if other alloying elements decrease in availability, is of great importance.

24. HARVEY, T. G. *Effect of Boron on Machinability and Hardenability.* Iron Age, v. 155, February 15, 1945.
25. ZLATIN, N., et al. *How Do Boron Steels Compare in Machinability?* Iron Age, v. 172, October 1953.
26. ZATCZAK, C. F., and ROWLAND, E. S. *The Influence of Boron on Case Hardenability in Alloy Carburizing Steels.* Trans. ASM, v. 45, 1953.
27. GRANGE, R. A., and MITCHELL, J. B. *Effect of Carbon and Boron on the Hardenability of a Case-Carburized Steel.* Trans. ASM, v. 46, 1954.
28. COTTRELL, C. L. M. *Weldability of a B-Mo Steel Related to Properties of the Heat Affected Zone.* British Welding J., v. 1, 1954.
29. KNOWLTON, H. B. *Experiences with Boron Steels in Production.* Metal Progress, v. 63, 1953.
30. STONE, P. G., and MURRAY, J. D. *Creep Ductility of Cr-Mo-V Steels.* J. Iron and Steel Institute, v. 203, November 1965, p. 1094.

Table 3 is a 1972 summary of the U.S. dependence on foreign supply of alloying elements for alloy steels.[4] Molybdenum is available domestically in greater quantities than required. U.S. production was nearly two thirds of the world production for the year; almost half was exported, and the remainder exceeded domestic consumption demands. Domestic sources of manganese, however, are almost nonexistent. In 1972, 95% of the manganese required for alloy steels had to be imported since domestic production of the metal was less than 1% of world production. Similarly, adequate quantities of nickel are not available domestically and U.S. production was only 2% of the world production. This required that 75% of the consumption needs for 1972 had to be imported. The chromium situation is even worse since there is no U.S. production, and all chromium must be imported. In 1972, U.S. imports amounted to 11% of the world production. Silicon and vanadium are used in very small amounts in alloy steels and are available from domestic sources. It is noted in Table 3 that the United States exported vanadium in the same quantity imported, thus no availability problems are expected. Since the U.S. produces 98% of the world's boron, and its use in alloy steels is in such small percentages, no availability problem exists. Manganese, nickel, and chromium, then, are the alloying elements in structural alloy steels for which wartime availability concern is greatest.

Manganese

More than one third of the world's manganese production is from the Soviet Union. Another third is produced in Africa, a tenth in South America, a tenth in India, and nearly a tenth in Australia. For the past three or four years, production from each of these areas has been rather stable except for Australia which has doubled its production.[4] During 1972, 55% of U.S. imports came from Africa (Gabon, Zaire, and South Africa) and 25% from Brazil. Based on recent world history, U.S. supply from these sources will probably be available indefinitely. In addition, expansion of Australian mining would probably be expedited

Table 3. STEEL ALLOYING ELEMENTS

World and Domestic Production and Use in 1972

	World Production (Short Tons)	U.S. Production (% of World Production)	U.S. Use (% Imported)
Molybdenum	87,500*	64	0
Manganese	22,830,000†	0.5	95
Nickel	700,000*	2	75
Chromium	2,200,000*	0	100
Silicon	>500,000	∿80	0
Vanadium	20,000	25	‡
Boron (Minerals)	1,121,000	98	0

*In terms of element weight
†Ore concentrates (>35% Mn)
‡10% of U.S. production is also exported. Thus, imports are not essential.

NOTE: 1. Nickel recovered from domestic scrap totaled 36,000 tons in 1972.
2. Domestic reserves of silicon, boron, and molybdenum are adequate.
3. Domestic production of chromium stopped in 1961; imports in 1972 were 353,000 tons of chromium metal content.

in wartime. Finally, it is now considered feasible to mine manganese nodules from the ocean floor, but this technology could be developed.[4] These facts coupled with the average manganese level in steel scrap provide comforting assurance of an adequate manganese supply.

Of the manganese consumed in the United States, about 90% is used in the iron and steel industry and the remaining 10% is used in batteries and chemicals. That used in ferrous metals is almost all in the ferromanganese form, and its use distribution is shown in Table 4. Note that about 60% of the total is used in plain carbon steels and about 40% is used in alloy steels. All alloy steels contain manganese in the range of 0.40% to 1.10% except for the 13XX series which contains 1.45% to 2.05%.[10] Even the standard grades of boron steels contain 0.65% to 1.10% manganese because manganese is such an important alloying element for minimizing hot shortness and for strengthening ferrite. Thus, large savings of alloying elements due to boron additions will come from reductions of alloying elements other than manganese.

In 1972 the national stockpile of metallurgical grade manganese ore was nearly 8,000,000 tons. This represents more than a 3-year supply based on 1972 consumption of 2,300,000 tons of ore. By the end of 1973 the national stockpile had been reduced to 4,500,000 tons, or about a 2-year supply.[31] However, the stockpile objective is only 950,000 tons, or less than a 6-month supply.[31] This is a very small objective for a national stockpile item that is not available domestically and is of such vital importance to the steel industry. Since almost all steel scrap contains 0.50% to 1.0% manganese, steel scrap may be of critical importance in the event of a future war, simply as a source of manganese.

Chromium

The Soviet Union produces nearly 30% of the world's chromite (chromium ore), with another 30% being produced in Africa (Rhodesia and South Africa). Turkey and Albania each produce about 10% of the world's supply, while the Philippines and India each produce about 5%. World production of chromite ore in 1972 was 6,800,000 tons, and total U.S. consumption was about 1,000,000 tons or about 15% of the world production. Domestic production of chromite was discontinued in 1961 when the last Defense Production Act contract was phased out. Thus, the

Table 4. U.S. CONSUMPTION OF FERROMANGANESE IN 1972

End Use	Gross Weight (Short Tons)
Carbon Steels	660,000
Full Alloy Steels	104,000
Low Alloy Steels	68,000
Cast Irons	18,000
Stainless Steels	9,000
Alloys	6,000
Tool Steels	2,000
Miscellaneous	2,000
Total	869,000

31. SAMPSON, A. F. *Stockpile Report to the Congress.* GSA Report, July-December 1973.

United States is currently totally dependent on imported chromite, but could re-initiate mining of low-grade domestic ores to provide for a small portion of its needs in the event of a major war.[4]

Of the chromium consumed in the United States, about 65% was used in the metallurgical industry, 20% was used by the refractory industry, and 15% by the chemical industry. Table 5 contains use distribution of that portion consumed by the metallurgical industry (730,000 tons of chromite contains 239,000 tons of chromium metal). Almost 70% of the metallurgical chromium is used in stainless steels to provide resistance to corrosion. Nearly 20% is used in alloy steels, with the remaining 10% being used in a variety of items.[4] The chromium used in alloy steels (nearly 50,000 tons in 1972) is a candidate for alloy conservation by increased use of boron steels.

In 1972 the national stockpile of metallurgical grade chromite ore (including the Defense Production Act portion) was 1,550,000 tons with a stockpile objective of 2,900,000 tons. This represented a 1-1/2-year supply with a 3-year objective.[4] By the end of 1973 the total stockpile inventory was 3,400,000 tons, but the national objective had been reduced to 450,000 tons. Legislation is pending to dispose of the surplus.[31] Such reserve stock depletion might be considered dangerous to the national interest in spite of the recent discoveries in the Stillwater Complex of southwester Montana.[32] The Stillwater deposits contain more than 7-1/2 million short tons of low-grade chromite ore along with recoverable platinum group metals.[32] Thus, the national stock depletion of chromite appears to be a tolerable action with respect to availability of chromium for alloy steels only if the Stillwater chromite can be mined and processed within a short lead time.

Nickel

Almost 40% of the world's nickel production in 1972 was from Canada.[4] The Soviet Union produced 20% of the world total, New Caledonia 16%, Cuba and the Dominican Republic about 10%, and Australia about 6%. Since domestic production of nickel is only 2% of the world total, and U.S. consumption is 23% of the world production, extensive imports were necessary. Of these imports, 80% were from Canada, a relatively safe source of supply in wartime. During the past few years,

Table 5. U.S. CONSUMPTION OF CHROMIUM IN 1972

End Use	Chromium (Short Tons)
Stainless Steels	166,500
Full Alloy Steels	37,000
Low Alloy Steels	10,000
Super Alloys	7,500
Cast Irons	6,000
Tool Steels	3,000
Carbon Steels	2,500
Other Alloys	3,500
Miscellaneous	3,000
Total	239,000

32. Geological Survey Circular 684, U.S. Bureau of Mines, 1974.

nickel mining operations have been expanded to the point where supply exceeds demand.[4] Planned expansion of mining operations in Canada, Australia, and New Caledonia was curtailed in 1972. Extensive high-grade ore reserves exist in all three countries.

Of the 159,000 tons of nickel consumed in the United States in 1972, 30% was used in stainless steels, 24% in nickel alloys, 18% for electroplating, 12% for alloy steels, and 8% for super alloys.[4] This end use distribution is contained in Table 6. Of these uses, only the alloy steels offer potential for conservation measures by boron steel substitution, but the savings potential is substantial since several alloy steel classes contain in excess of 3% nickel.[10]

In July 1972 the President approved legislation that authorized disposal of all nickel held in the national stockpile. By the end of 1973 all nickel was disposed of and the stockpile objective of no nickel was achieved. Apparently world reserves in friendly foreign nations are sufficient for the national interest in the immediate future.

Molybdenum

The U.S. produces 64% of the world's molybdenum, consumes only half of what it produces, and exports the other half. Canada produces 14% of the world's molybdenum, Soviet Russia 10%, Chile 7%, and China 2%. There does not appear to be any problem regarding availability of molybdenum for metallurgical uses in the immediate future since domestic reserves are extensive.[4]

Domestic consumption of molybdenum is summarized in Table 7. Note that more than 40% is used in alloy steels. Because of the national surplus of molybdenum, however, increased use in alloy steels would be recommended in order to conserve nickel and chromium.

The national stockpile of molybdenum was eliminated in 1973 when Public Law 93-219 was signed and the disposal of 18,000 tons of molybdenum was authorized.

Table 6. U.S. CONSUMPTION OF NICKEL* IN 1972

End Use	Nickel (Short Tons)
Stainless Steels	45,500
Nickel Alloys	37,500
Electroplating	29,000
Alloy Steels	19,500
Super Alloys	12,000
Cast Irons	4,500
Magnet Alloys	4,000
Chemicals, Batteries, Ceramics	7,000
Total	159,000

*Commercially pure nickel with some ferro-nickel and nickel oxide quantities.

Vanadium

About one fourth of the world's vanadium production in 1972 was domestic (Table 3). U.S. consumption was also about one fourth of the world production. About a tenth of the U.S. production was exported and an equal amount of vanadium was imported. Domestic sources of vanadium are ample, and production seems to be well geared to demand. During the past few years vanadium mining operations have been reduced. Most vanadium is now obtained by processing oil residues, spent catalysts, and residues from titanium and uranium ores.[4]

Of the vanadium consumed in this country, almost 85% is used in steels, with 70% of that used in alloy steels as illustrated in Table 8. Vanadium additions to steel promote deoxidation and grain refinement in amounts up to about 0.50% and are important for boron steels.[10] Both vanadium and molybdenum reduce susceptibility to temper embrittlement and would be important to use in boron steels of reduced nickel content.

The national stockpile of vanadium was abolished at the end of 1972 and the 2800 tons in the stockpile at that time were disposed of. There is currently no national stockpile objective for the element.

Silicon

More than 25% of the mass of the earth's crust is silicon. It is readily available as SiO_2 in a variety of sands and rocks in the United States as well as in most countries. No availability problems are anticipated with this element.

Table 7. U.S. CONSUMPTION OF MOLYBDENUM IN 1972

End Use	Molybdenum (Short Tons)
Full Alloy Steels	8,500
Stainless Steels	3,000
Cast Irons	2,000
Tool Steels	1,500
Low Alloy Steels	1,500
Mill Products	1,250
Super Alloys	1,250
Other Steels	1,000
Chemicals and Ceramics	2,500
Total	22,500

Table 8. U.S. CONSUMPTION OF VANADIUM IN 1972

End Use	Vanadium (Short Tons)
Low Alloy Steels	2,000
Full Alloy Steels	1,100
Carbon Steels	650
Tool Steels	650
Cast Irons and Super Alloys	100
Nonferrous Alloys	400
Ceramic Catalysts	100
Other	200
Total	5,200

Cost Benefit Potential

Because of the current inflation rate and the slight price variations between companies, cost figures used in this section are several years old. However, what is important here are the percentage cost savings which can be achieved with boron steels. The exact cost savings for a specific part would have to be computed at the time of use and may be somewhat larger or smaller than indicated in this report.

Steel prices are computed from a base price for the general steel type plus extras which are added for control of chemistry for alloying elements and other services such as heat treatment and surface finish which may be desired. Considering alloy steels and the compositional control price extras only, the following costs are provided (1972-1973) for certain alloy steels.

Alloy Designation	Base Price ($/cwt)	Extra ($/cwt)	Cost ($/Ton)
1345H	14.20	0.90	302.00
4140H	14.20	1.95	323.00
4130	14.20	1.75	319.00
8630	14.20	2.70	338.00
8640	14.20	2.70	338.00
8670	14.20	2.85	341.00

It is noted that for these specific steels the price range was from about $300 to $340 per ton.

At the same time, the base price for carbon steels was $9.15 per cwt with extras of $0.25 for carbon, $0.65 for "killed," $0.30 for "fine grain," and $0.20 for "forging quality." This represents a base price of $10.55 per cwt or about $210.00 per ton. When boron and manganese extras are added to carbon steels, the extras involved were $0.25 for boron and $0.70 for manganese (over 1.50%). Thus a killed, fine-grained boron steel of forging quality sold for $11.50 per cwt or $230.00 per ton. At the time, a similar low alloy steel was selling for $300.00 per ton.

A simple cost comparison table follows:

Steel Type	Cost ($/Ton)	% Savings Over Alloy Steel
Alloy	340.00	-
Low Alloy	300.00	12
Carbon Boron	230.00	32
Carbon	210.00	38

For many, if not most, alloy steel applications plain carbon steels could not be substituted because they would lack sufficient toughness. If they were substituted, a large number of fractures would be expected in service resulting in inadequate hardware reliability. However, in most cases either a low alloy or carbon boron steel could be substituted with a cost savings benefit of 10% to 30% in material cost. There are many commercial boron steels which contain small amounts of alloying elements, and the cost extras of these steels would make their cost intermediate between carbon-boron and low alloy steels. Thus cost savings of 10% to 30% are realistic.

It must be emphasized, however, that there are a few hardware parts of such large section thickness that they require very high hardenability. For these parts, use of a boron steel as a substitute for an alloy steel may not be feasible. It would, of course, be necessary to make a critical evaluation of the materials engineering ramifications for the part and its service use in order to determine the feasibility of a substitution.

STANDARDIZATION STATUS

Boron steels have been accepted by industry and used for many years in a great variety of commercial and automotive applications. As an example of commercial use and acceptability of boron steels, a 1954 article in the Journal of the Iron and Steel Institute entitled, "American Applications of Boron and Other Low Alloy Steels" contains an entensive list of parts where boron steels have been used. The parts include those receiving quench and temper heat treatments as well as some which were case carburized. Since 1954, boron steels have been used in many other similar applications in the farm machinery and automotive fields with very satisfactory performance.

There are numerous specifications which cover boron steels, and which are approved for use in the Department of Defense. Table 9 lists selected representative specifications from the many available. Specification MIL-S-11415(ORD) is the Government specification for steel parts and has been in existence since 1951. It contains many boron steel designations which are considered interchangeable with non-boron steels made to guaranteed hardenability limits. The other specifications in the table are AMS and ASTM specifications either for boron steels, or for which boron steels are interchangeable with other steels. These particular specifications have been approved (along with many other ASTM and AMS specifications) for use by the Department of Defense as equivalent to MIL specifications.

From the above brief paragraphs it is clear that not only is there commercial experience with applications of boron steels to structural applications, but also that specifications exist for procurement of boron steels for military use.

Table 9. SPECIFICATIONS FOR BORON STEELS

Document No.	Date of Issue
MIL-S-11415(ORD)	9-4-51
AMS 6321	11-1-51
ASTM A400-69	1956
ASTM A514-70	1964
ASTM A517-72	1964

CONCLUSION AND RECOMMENDATIONS

Based on the literature reviewed in the preparation of this report, it is concluded that boron steels can be used in place of alloy steels for many Army hardware applications in order to achieve conservation of critical and/or strategic alloying elements without decreasing component reliability. For each application the substitute boron steel composition selection would be made primarly on the basis of hardenability; but if welding of the component part was required in fabrication, the carbon content may have to be limited in the interest of weldability. However, such factors would be included in the materials engineering evaluation for the boron steel alloy selection.

Because of the dependence on foreign sources of certain steel alloying elements, their increasing cost, and the President's recent press release suggesting the use of less expensive steels in military hardware, the following recommendations are made to assist in greater use of boron steels as well as to facilitate mobilization planning:

1. Review military specifications for boron steels and update as required.

2. Compile a handbook of composition and hardenability band data for commonly used alloy steels and the boron steels which could be utilized as substitutes.

3. Conduct a study of large tonnage use of specific alloy steels for military hardware parts and define the specific boron steels which would be acceptable substitutes, indicating both the tonnage of critical and/or strategic alloys and cost savings which could be achieved by substitution.

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